# ONTARIO'S PROGRAM ON THE LONG RANGE TRANSPORT, DEPOSITION, EFFECTS AND CONTROL OF AIR POLLUTANTS

## MULTI-YEAR PLAN 1986-1990

APIOS 007/86



Ontario

Ministry of the Environment

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# Ontario's Program on the Long Range Transport, Deposition, Effects and Control of Air Pollutants

Multi-Year Plan
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# PREFACE

Studies of the acidification of surface waters and vegetation damage near the large sulphur dioxide emitters at Sudbury have been carried out for many years. In 1972, Ontario began a coordinated atmospheric, terrestrial and aquatic study called the Sudbury Environmental Study. The objectives were to define the nature and extent of damage and to recommend further control actions. Final reports were published in 1982.

In recognition of the fact that many pollutants were being carried into Ontario by long range atmospheric transport, an expanded study was established in 1979. The Acidic Precipitation in Ontario Study (A.P.I.O.S.) included emissions inventories, transport mechanisms, deposition, terrestrial effects, aquatic effects, socioeconomic studies, information programs and legal initiatives.

The overall mandate of the program is to protect Ontario's environment from the detrimental effects of acid precipitation and other air pollutants subject to long-range transport.

The project initially focussed on acidic pollutants and a two-year preliminary phase was developed. At the end of Phase 1, it was determined that the program needed to continue for a minimum of five additional years (Phase 2) and a five year projection of activities was developed in 1982.

Since the start of this work, there has been increasing evidence concerning the environmental effects of oxidants (ozone) and of organic chemical contamination from long range transport. Ontario's LRTAP strategy which was approved by the Ministry's Executive Committee in December 1981 "to effect reductions in emissions of $SO_2$, $NO_x$, $O_3$, hydrocarbons, organic compounds, metals and other pollutants on a continental North American basis", encompasses these pollutants as well.

Therefore, this revised study plan takes into account the many changes in program activities brought about by new information from previous work both within A.P.I.O.S. and from other studies and now better reflects the original mandate.

## LONG RANGE TRANSPORT OF AIR POLLUTANTS PROGRAM

### PURPOSE

The purpose of the L.R.T.A.P. program is to protect Ontario's environment from the damaging effects of long range transport of air pollutants, their atmospheric transformation and their deposition.

### OBJECTIVE

To develop and implement an emission control program to protect the Ontario environment from detrimental effects of the long range transport of air pollutants, their atmospheric transformation and their deposition, with particular emphasis on acids and acid precursors.

### GOALS

1. To develop and implement a specific emission control plan for Ontario which must be compatible with the eastern Canadian control plan.

2. To support the federal government in negotiating a U.S. control plan.

3. To monitor the environmental response to emission reductions.

4. To document and predict the chemical and biological effects of atmospheric deposition of pollutants on aquatic ecosystems throughout Ontario.

5. To investigate interim strategies for the protection and rehabilitation of damaged aquatic ecosystems.

6. To determine the effects of atmospheric deposition of pollutants and associated ambient air quality on terrestrial ecosystems including soil biogeochemistry, forests and agricultural crops.

7. To maintain an inventory of information on the human health effects of the acidic precipitation phenomenon.

8. To investigate the phenomena of atmospheric chemistry, transport and deposition of air pollutants especially those related to acid and acid-forming materials. The relationship between sources in North America and Ontario receptors, as connected by long-range transport, meteorological factors and chemical transformation processes, is to be quantified.

9. To investigate the costs and benefits of alternative air pollution strategies.

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EXECUTIVE SUMMARY

Ontario's environmental studies have already proven that sulphate deposition resulting from sulphur dioxide emissions is the primary cause of surface water acidification. As a result, Ontario is now taking significant further steps to curb the long range transport of $SO_2$. Province-wide emissions of $SO_2$ will be cut by the year 1994 by well over half, compared to the 1980 base case value of 2,194 kilotonnes. For more information on Ontario's control program, please refer to the "Countdown: Acid Rain" report.

The individual projects in the LRTAP program have been designed to deliver results in order to:

- prove, document and assess environmental impacts;
- identify and document sources of pollution;
- establish standards for impact mitigation;
- establish abatement standards for sources;
- establish and assess experimental techniques for lake neutralization;
- establish methods and determine social importance and economic costs;
- develop procedures to specify policies and control programs;
- assess legal instruments and intervene in the U.S. system when applicable;
- develop information material for use in Ontario, Canada and the U.S.

The fundamental data gathering programs for emissions, deposition and surface water chemistry are well established.

Atmospheric studies have progressed to developing sophisticated models for predicting the effects of various control options. Model evaluation will be carried out during the next three years.

Surface water acidification mechanisms have been determined to a large degree but the rates of change and the ultimate safe deposition values are still subject to much controversy and study.

In the past two or three years, there has been a mounting concern for forest damage which could be related to air pollution/acid rain. Enhanced research and monitoring in the terrestrial program reflect these new observations and concerns.

Most recently, there has been increased interest in the role of oxides of nitrogen and their ultimate impact on the acidification process (spring shock; the formation of ozone in the atmosphere; damage to forested ecosystems).

More focus will also be given to the causes and effects of heavy metal contamination during the next few years.

The detailed biogeochemical study sites are providing critical data for both the surface water acidification and forest damage studies.

There is heightening concern for possible environmental effects caused by the long range transport of organic chemicals. Additional activities in emissions and deposition measurements and in aquatic and terrestrial studies are in response to this emerging problem.

Ontario's LRTAP scientific research program over the next five years has been developed:

- to strengthen the ability to predict the relationship between sources and receptors for abatement purposes;
- to provide increased evidence of aquatic damage;
- to expand the inventory of aquatic impacts in sensitive areas;
- to monitor long term effects of lake neutralization;
- to focus, expand and coordinate with other agencies, research on forest damage;
- to strengthen biogeochemical modelling to predict effects on water, soil and vegetation.

Ontario's program also includes socioeconomic, legal and public relations initiatives.

The socioeconomic component is designed to provide frameworks and methods to integrate scientific and socioeconomic data and information to produce policy-relevant assessments of control strategies.

The legal component involves the preparation of provincial Regulations for control of Ontario's internal sources as well as interventions in the U.S. system to 1) prevent a relaxation in $SO_2$ limits and 2) to urge the U.S. Environmental Protection Agency to take action under relevant sections of the U.S. Clean Air Act.

The public relations initiatives are designed to keep the Ontario populace informed of provincial activities concerning acid rain as well as to provide U.S. citizens with information on Ontario's acid rain problem and control program.

The following detailed descriptions of the individual tasks include revised objectives, achievements to date and planned future activities. It should be noted that the 'achievements to date' sections are being measured against the objectives in the APIOS Multi-Year Plan prepared in 1982.

## TASK 1. ATMOSPHERIC PROCESSES STUDIES

### A. Emissions Inventory

Objectives:

1. To compile the most up-to-date acid rain related pollutant emission data (both natural and anthropogenic) for Ontario and North America.

2. To provide good quality emission data for input to the long range transport/acid rain modelling activities.

3. To provide accurate emission information for decision making purposes.

4. To monitor the trend of acid rain related emissions in Ontario and North America.

5. To compile emission inventories for ammonia, alkaline dust-related substances and trace metals for use in the Eulerian model.

6. To estimate $NO_x$ and hydrocarbon emissions from a typical Ontario car population.

Achievements to Date:

An Ontario Acid Rain Emission Inventory (OAREI) system has been implemented. This computerized data management system accepts, stores and reports on recent available emission information of sulphur dioxide, oxides of nitrogen, volatile organic compounds, carbon monoxide and particulates. The emission data can be spatially resolved on a 127 $km^2$ grid (or finer) and temporally on a seasonal, weekly or daily basis. The contents of the inventory cover all point and area sources. Data from the inventory system have been used in support of long-range transport modelling studies, by various government agencies for their decision-making purposes and for various technical studies.

The current inventory system contains up-to-date and comprehensive information for sulphur dioxide and nitrogen oxides for Ontario as well as North America.

For the U.S., a detailed file of the electric utility sector has been compiled for the years 1972 to 1983 inclusive. Historical trend analyses for this period are being conducted. The most recent data bases from the U.S. E.P.A. have been checked, matched and merged to the inventory for the base-year 1980. In addition, routine procedures for quality assurance have been established to improve the reliability of the emission information.

A detailed inventory of area $NO_x$ emissions in Ontario has been completed. Similar methodologies were adopted for the compilation of sulphur dioxide, hydrocarbon,

carbon monoxide and particulate emissions. Historical trends in area source emissions in Ontario for the period 1970 to 1983 are being investigated.

A detailed inventory of volatile organic compounds (VOC) in Ontario has also been completed for the base year 1980. This inventory contains VOC species information (in excess of 160 compounds grouped in fourteen classes) emitted from both man-made and natural sources. The data can be resolved temporally and spatially.

Planned Future Activities:

Future inventory tasks will include:

- on-going maintenance and development of the OAREI System;
- processing and integration of the VOC emissions into the main Ontario acid rain data base;
- development of a special base year (1985) Ontario emissions inventory for the next generation of acid rain models;
- provision of detailed emission inventories for the PEPE/NEROS (August 1980) and OSCAR (April 1981) study periods as required for the Eulerian model validation work;
- compilation of detailed Ontario inventories for ammonia, alkaline-dust related substances and trace metals.

**B. Modelling Studies**

Objectives:

1. To develop validated atmospheric models that will simulate the transport and wet and dry deposition of acidic pollutants.
2. To apply models for the development of abatement strategies.
3. To interpret atmospheric deposition measurements indicating the impact from Ontario and outside-the-Province sources using the above-mentioned models, up-to-date emission inventories of the contaminants and meteorological information.
4. To provide modelling input for field investigations.
5. To provide modelling advice to other groups working on the acidic precipitation problem in Ontario and outside the Province.
6. To determine uncertainties in model outputs and their implications on regulatory decision making.

Achievements to Date:

A statistical LRTAP model has been developed and validated. This model simulates long-term deposition and is designed to establish source-receptor relationships resulting from the transport of contaminants over distances of hundreds of kilometers. Input involves climatic statistics and annual emissions. The model was evaluated in the Canada-U.S. Memorandum of Intent (MOI) Work Group II model evaluation workshop and has been improved by the incorporation of plume height and vertical dispersion to properly account for tall stack impacts and dry deposition. The model has been used to provide support in various legal actions involving Ontario and out-of-Province sources. It is currently being used extensively for abatement studies. The model is also used by the U.S. States of New York and Minnesota.

A Lagrangian model has been developed and evaluated with three years of deposition data. The model has been used to produce transfer matrices for use in abatement strategies and for the analyses of data to determine Inco's contribution to wet sulphur deposition at Muskoka.

A non-linear chemistry scheme is being developed to be used with the Lagrangian model to determine the extent to which non-linearity affects deposition of sulphur and other acidic compounds.

A mesoscale wind field model has been developed. It will be used in conjunction with the Lagrangian model to determine the local impacts of sources.

An Eulerian long range transport model incorporating state-of-the-art modelling techniques in transport chemistry and scavenging is being developed. A working version of the model is being implemented in the CRAY computer at the Canadian Meteorological Centre in Dorval. The model will be evaluated with OSCAR and PEPE/NEROS data during the period of April 1, 1985 to March 31, 1986.

The Eulerian model is co-sponsored by Environment Canada, the Federal Republic of Germany and the State of Minnesota.

A number of scientific papers were published in refereed journals and presented at scientific conferences related to the above model development projects.

MOE took an active role in the Canada/U.S. MOI model evaluation exercise.

Planned Future Activities:

Future modelling activities include the following:

- The Statistical and Lagrangian models will continue to be used for abatement strategies and will be evaluated with additional data as they become available.

- The Lagrangian model with the non-linear chemistry package will be used to study the effects of non-linearity on the deposition of acidic pollutants.

- The Eulerian model will undergo evaluation with OSCAR and PEPE/NEROS data from April 1, 1985 to March 31, 1986. It will be evaluated further as new field studies are carried out and additional data are collected. Once evaluated, it will be used for source control applications.

- The mesoscale model will be improved to study the local effects of sources.

- MOE will participate in joint workshops with the U.S. EPA and NCAR to evaluate the Eulerian models currently being developed.

**C. Deposition Monitoring Networks**

Objectives:

1. To determine the long-term spatial and temporal trends in wet and dry deposition fields in Ontario of acids and other pollutants related to long range transport, such as trace metals and persistent organics, and to identify regions of Ontario that are currently receiving high levels of acid deposition.

2. To determine the frequency and intensity of acidic deposition episodes in Ontario (both wet and dry) and to characterize the atmospheric conditions which result in high acid deposition episodes.

3. Through a combination of event deposition monitoring and meteorological analysis, to carry out directional source identification (i.e., to determine deposition associated with air masses originating in different compass sectors).

4. To determine the impact of certain major Ontario sources (such as Inco and Hydro's Nanticoke generating station) on downwind atmospheric deposition and precipitation chemistry.

5. To provide data for validating long-range transport mathematical models.

6. To provide information on atmospheric deposition to other groups, including those within Ontario and at the national and international levels.

7. To carry out special field programs in support of modelling and effects studies and to elucidate atmospheric processes related to acid rain formation.

Achievements to Date:

As part of the deposition monitoring program, the following tasks have been completed:

- An intercomparison with CANSAP and CCIW networks regarding precipitation sampling in 1979 and 1980 was carried out.

- Precipitation networks were set up to sample wet deposition and air concentration on daily and cumulative (monthly at the inception of network and 28 day as of January 5, 1982) bases. The 28 day network has 36 stations to sample precipitation; 23 of the 36 also sample air concentrations. The daily network has 15 stations to sample precipitation; four of the 15 also sample air concentrations.

- Intercomparison studies of precipitation monitoring were undertaken in conjunction with NADP, Environment Canada, Environment Québec and Ontario Hydro from 1982 to 1984.

- An intercomparison study of daily air concentration measurements was undertaken with Environment Canada and Ontario Hydro in 1981 and 1982.

- The Ministry participated in an intercomparison study of dry deposition measurement techniques sponsored by the U.S. Environmental Protection Agency in 1982.

- A comprehensive quality assurance program was implemented for the monitoring program, which included three field/lab/data management audits by an external auditor.

- A preliminary precipitation mercury monitoring program was completed at Forbes Township (Northwestern Region) and Dorset (Central Region).

- Developmental work was initiated for sampling of organics in precipitation.

- An APIOS deposition data base for precipitation and air data storage was established.

- Regular data exchanges were initiated with other Canadian (CANSAP and Ontario Hydro) and international (NADP and MAP3S) networks.

- Data were provided to the meteorology, modelling, terrestrial effects, aquatic effects and socio-economic groups.

- Regular data listings, statistical and contour reports of data from both the precipitation and air sampling networks were published. (Data up to 1983 are currently being published.)

- A report was prepared on the assessment of the Sudbury smelters' impact on wet and dry deposition in Ontario.

- Papers were published in international journals on sampling, instrumentation, acid deposition episode analysis and source impact analysis.

- Papers were presented at international conferences on sampling, instrumentation and methodologies, wet and dry deposition, quality assurance and source assessment.

- Program members served as review panelists on the U.S. NAPAP and Environment Canada LRTAP programs.

In summary, the network of air and precipitation samplers is now fully operational across the province. A quality assurance program is in place, as are data storage, retrieval and validation procedures. Listings of the data from the network, as well as data analysis and interpretation reports, are being published on a regular basis. A sound data base is being assembled and used for:
(1) delineating which areas of the province are receiving unacceptable acidic loadings from the atmosphere;
(2) identifying sectors of origin for air parcels causing high acid deposition at sensitive Ontario receptor areas;
(3) determining the impact of large Ontario sources such as the Inco and Falconbridge smelters at Sudbury; and
(4) determining trends in atmospheric deposition in Ontario.

Planned Future Activities:

Future monitoring activities include:

- maintaining high quality in wet and dry deposition monitoring;

- developing analysis methods to study deposition in order to characterize acid deposition episodes, to evaluate trends and to assess source impacts;

- developing sampling methodologies for sampling of other long range transport pollutants such as trace metals and persistent organics;

- publishing reports on monitoring data and timely interpretations.

**D. Oxidants Strategy Development**

Objectives:

1. To document the extent of oxidants damage in Ontario.

2. To identify the meteorological conditions associated with high oxidants levels in Ontario.

3. To develop an inventory of oxidant precursor emissions, including hydrocarbons and nitrogen oxides, from the Ontario transportation sector.

4. To provide input for the development of an abatement strategy for oxidants in Ontario.

Achievements to Date:

The following has been accomplished as part of this task:

- an assessment of ozone effects on crops in Ontario (Report ARB-13-84-Phyto);
- meteorological analyses of ozone episodes in Ontario, using data to the end of 1981;
- the development of an emissions inventory for nitrogen oxides and hydrocarbons in Ontario;
- improvement of emissions data for $NO_x$ and hydrocarbons from the transportation sector, through support of the MOE emissions testing program;
- preliminary mathematical modelling of ozone formation in the Toronto, Sarnia and Windsor areas to evaluate control strategies for hydrocarbons and $NO_x$;
- organization and execution of an intensive field study in the Sarnia area (June/July 1984) to determine the relative contribution of Sarnia emissions and long-range transport from the United States to the oxidant problem in Southwestern Ontario.

The status of the oxidants strategy development task has been assessed and areas requiring further work have been identified. These are outlined below and when they have been completed it should be possible to make a recommendation on how best to control the oxidants problem in Ontario.

Planned Future Activities:

Future activities in this area include:

- updating of the work on transport and transformation of ozone and ozone precursors as well as an extension of the ozone episode analysis to include data to the end of 1983;
- updating of the work on damages and related costs, including an assessment of the damage of air pollutants to forests in Ontario;
- application of mathematical air quality models with detailed photochemistry, in conjunction with data from the Sarnia Oxidant Study (June/July 1984), to assess various emission control strategies (i.e. hydrocarbons versus nitrogen oxides) in an Ontario setting;
- production of a report with recommendations on how best to control oxidants in Ontario.

## E. Meteorology Studies

Objectives:

1. To provide meteorological support for modelling and field studies and for the interpretation of deposition monitoring data.

2. To provide meteorological advice to other groups, in Ontario and outside.

3. To acquire and archive meteorological data to provide necessary input for modelling activities, meteorological studies and historical trend analyses.

Achievements to Date:

A meteorological data acquisition system (MDAS), capable of providing support for special studies and episode analysis, as well as modelling activities, has been implemented. This computerized system collects and stores meteorological data supplied by Environment Canada from its network of meteorological stations. The area covered by MDAS extends approximately east of the Rockies and north of Florida. Air parcel trajectories, terminating or originating at a specific location, can be calculated by the system for interpreting event precipitation and other air quality data. To date, trajectory analyses have been provided for events at various locations in Ontario and Eastern North America.

The influence of meteorology on the deposition of acidic pollutants has been investigated. Meteorological analyses of precipitation and air quality data for the period 1976 to 1983 have been undertaken using techniques such as air parcel trajectory modelling and synoptic weather classification systems to infer potential source regions of acidity in Ontario. In this regard, MDAS has been used to provide historical and real-time trajectory statistics.

Long term and episodic studies for the areas of Southern and Central Ontario have been completed.

During FY 1983/84 and 1984/85, MOE assisted the Atmospheric Environment Service in providing air parcel trajectories for the "acid rain" bulletin which is distributed to news media in Eastern Canada. Air parcel trajectory statistics were also provided to Environment Québec for their acid rain studies in 1984.

The computerized plotting facilities of MDAS are also being used in support of mapping water and soil chemistry data across Ontario.

Planned Future Activities:

Future meteorological tasks will include:

- continued maintenance and enhancement of the Meteorological Data Acquisition System;
- analyses to determine relationships between meteorological and precipitation chemistry and air quality data;
- acquisition and archiving of meteorological data on an on-going basis to provide support, input and advice for various acid rain related activities.

## TASK 2. AQUATIC EFFECTS STUDIES

Overall Goal for Aquatic Studies:

To continue to document and predict the impacts of atmospheric deposition on selected characteristics of aquatic ecosystems throughout Ontario, with emphasis on acidic deposition and related contaminants.

### A. Calibrated Watersheds

Objectives:

1. To refine models that have been developed to predict the impact of atmospheric deposition on chemical parameters such as pH, alkalinity and aluminum and to develop and refine models that predict the impact of atmospheric deposition of mercury and other metals and organic contaminants.

2. To continue development and refinement of models of the relationships between the chemical state of waters and their biota.

3. To determine the sources of metals, particularly mercury, and organic contaminants in lakes and to develop predictive models of the bioaccumulation of these contaminants in the food chain.

4. To predict both the geographic extent and rate of change in selected ecosystem characteristics and to document changes in state with parameters chosen on the basis of the best chemical and biological models.

i) Chemical Modelling

Achievements to Date:

Data are now available to resolve the role of natural or organic acidity in lake acidification. These data indicate that natural acidity plays a minor role in most waters of the Muskoka/Haliburton area.

The factors contributing to the spring pH depression have been quantified. They include sulphates, nitrates, organic acids and dilution by meltwater. Nitrates were found to be of minimal importance in many cases and organic acids also had a small role. In approximately 20 streams studied, sulphates and the dilution of stream alkalinity by low ionic strength meltwater were found to be the dominant factors in spring pH depression.

The processes which generate alkalinity in lakes have also been investigated. In Northwestern Ontario, most of the alkalinity appears to be generated within the lake itself. In the Dorset lakes, the watershed is the source of a significant portion of the alkalinity.

Some progress has been realized in determining the rate of change of lake chemistry. Unfortunately, the long term data are still inconclusive. After eight years of monitoring there has been no significant change, but the most sensitive lakes being studied have only four or five years of data. However, the rate of acidification appears to be slower than originally believed.

The other means of determining the rate of change is the use of models. One useful model is available for stream chemistry and flow and one is almost ready for lake chemistry. These models can be used to predict changes in parameters, such as alkalinity, pH, Ca and $SO_4$ under current loadings or under different scenarios of increased or decreased loadings.

Planned Future Activities:

- Long-term monitoring of calibrated watersheds will continue to determine the rate of loss of both lake and stream alkalinity in extremely and moderately sensitive watersheds under current deposition.

- Development will continue on a stream and lake chemistry model to predict rates of change in water chemistry under different acid deposition scenarios.

- A predictive model for lake alkalinity, based on relatively easily obtainable geological data, lake morphometry and watershed information is being developed. After testing, this will allow estimates of the number of lakes at risk in various areas of the province.

- The lake survey will be redesigned to include the physical and chemical data necessary for broadscale predictions of trends in lake chemistry necessary for economics and fisheries models.

ii) Chemical and Biological Relationships

Achievements to Date:

The effects of acidification on aquatic biota are primarily the result of the toxic effects of hydrogen ions and inorganic monomeric aluminum in waters low in base cations.

The toxicity of varying combinations of acid and aluminum has been determined on different life stages of several species of fish. Different fish species have widely varying sensitivity to acid and aluminum: for example, laboratory experiments have shown that white sucker and walleye are more sensitive than brook trout or smallmouth bass.

Amphibians such as toads, frogs and salamanders have also been assessed for their sensitivity to acidic conditions since they frequently use meltwater pools in which to lay their

eggs. Conditions in some of these meltwater pools were found to be toxic to salamander eggs.

Acidification has no apparent effect on macrophyte populations. Communities of benthic stream invertebrates are affected by observed levels of acid and aluminum, with some organisms such as mayflies and chrinomids being more sensitive than blackflies or caddisflies.

Water chemistry does have a marked effect on the composition of the phytoplankton and zooplankton communities. Several studies involving phytoplankton are discussed in Task 2B. One effect of acidification is that species such as dinoflagellates are favoured. There is evidence that these species are of little or no value to aquatic food chains. This may mean that a significant portion of the total nutrients and biomass may be tied up in algae species which cannot be used by fish or zooplankton rendering these lakes less productive for fish growth, although field data appear to refute the importance of this for fish growth. Zooplankton show reduced abundance and diversity in acidic lakes, but in Ontario, these effects seem to be limited to the Sudbury area.

For a review of the MNR studies concerning the effects of acid deposition on wildlife, see Task 2G.

Planned Future Activities:

- The occurrence of spring mortality in a pumpkinseed population in one of the study lakes has been repeatedly observed. A survey to determine how widespread this phenomenon is will be conducted.

- The effect of spring or fall pulses of low pH on survival of native fish will be studied and the lethal pH thresholds for the most sensitive stages of lake and brook trout will be determined.

- Work will continue in the area of determining lethal thresholds of $H^+$ and Al to early life stages of several fish species.

iii) Metal and Organic Contamination Studies

Achievements to Date:

Analysis of metal levels in fish from a number of lakes with varying water chemistry has revealed that fish in lakes with lower pH and alkalinity often contain higher concentrations of metals such as mercury, lead and cadmium. Sediment cores from a number of lakes in southern Ontario have shown that the upper layers are enriched with metals such as zinc, lead and cadmium. The occurrence of measurable levels of organic chemicals in fish from inland lakes indicates atmospheric deposition as a potential source of contamination.

Planned Future Activities:

- The mechanism by which metal enrichment of the food chain in acidified lakes occurs is not known. Studies to elucidate the mechanisms of uptake will be conducted.

- Extensive surveys will be conducted to relate water chemistry and atmospheric inputs to the levels of organic and inorganic contaminants in fish and other biota.

- Studies of the bioaccumulation of organic contaminants whose presence may be attributed to long range transport will be conducted to elucidate the pathway from the atmosphere to aquatic biota.

**B. Algal Studies**

Objectives:

1. To undertake extensive surveys and experimental work in the field and laboratory to determine growth conditions for filamentous algae.

2. To determine the cause/effect relationship for the occurrence of Chrysochromulina breviturrita Nich. in Ontario lakes. This algae causes severe odour problems in the lakes and restricts recreational use.

3. To examine the potential use of diatoms and scaled chrysophytes in lake sediments as indicators of past changes in lake alkalinity and pH.

4. To assess the impact of changes in phytoplankton community structure on the rest of the aquatic foodchain.

i) Filamentous Algae

Achievements to Date:

Certain species of filamentous algae are favoured by acidic conditions in lakes. So far, this has been verified by both experimental manipulations of lakes (both liming and acidification) and synoptic surveys.

Planned Future Activities:

Further work in this area will include assessment of the impact of lake neutralization and whole lake acidification (ELA) on filamentous algae communities.

ii) Odour Production

Achievements to Date:

A species of algae, first described in Ontario in the mid-1970's, can produce a very disagreeable odour. Research

to date has resulted in the isolation of a pure culture of this algae and some of the conditions for its growth have been defined. The algae requires a combination of low pH and relatively high selenium levels to thrive. Again, a combination of synoptic work, laboratory experiments and whole lake manipulation have all contributed to the understanding of the phenomenon.

Planned Future Activities:

° While the essential requirements for the growth of the odour causing algae are known, conditions which trigger a "bloom" of the algae are not known. Future work will include characterization of factors contributing to bloom formation and odour production as well as the role of inorganic nitrogen.

iii) Algal "Fossils" in Lake Sediments

Achievements to Date:

As the water chemistry of a lake changes, so does the composition of the algae community. Lakes of widely varying water chemistry have had their algae communities characterized and this "calibration" set is now being applied to sediment cores in acidified lakes to define the history of change in water chemistry, as reflected in algal remains in the sediment.

To date, diatom remains have been the most popular means of determining historic changes in lake pH. However, there is evidence that siliceous scales from chrysophyte algae can form an easier and more sensitive indicator of water chemistry changes. The application of this technique is now underway.

Planned Future Activities:

° A number of acidic lakes will have the history of their acidification reconstructed through an analysis of diatom and scaled chrysophyte remains in their sediments.

° The pH history of highly coloured lakes, where natural organic acids may be important, will be reconstructed. Work is required to characterize diatom and chrysophyte communities in these systems.

iv) Long-Term Phytoplankton Monitoring

Planned Future Activities:

° The impact of changes in phytoplankton community structure on the rest of the aquatic food chain will be assessed.

## C. Extensive Lake Sampling

Objectives:

1. To assess the current biological (specifically fisheries) and chemical (specifically pH and alkalinity) state of provincial waters and to document changes in state with parameters chosen on the basis of the best chemical and biological models.

2. To determine, on a broad scale, the relationship between lake chemistry and contaminant burdens in aquatic biota.

### i) Extensive Lake Chemistry Survey

Achievements to Date:

Well over 5,000 lakes have now been sampled in a cooperative MOE/MNR survey to determine their capacity to neutralize acid inputs. Based on the population of lakes sampled to date, several conclusions may be drawn. The general applicability of these conclusions has not been explicitly tested. The majority of lakes sampled for analysis of water chemistry on the Precambrian Shield have a very low acid neutralizing capacity (TIP 10 mg/l) most lakes in areas receiving significant amounts of acid deposition now have sulphate as the dominant anion. Lakes in areas of lower deposition still have bicarbonate as the dominant anion. Acidic lakes in the Sudbury area have shown decreases in acidity related to declines in $SO_2$ emissions from the Sudbury smelters.

Planned Future Activities:

- More lakes will be sampled, with emphasis on areas of Ontario which have little data and on poorly represented lake types.

- An optimum sampling program, including lake selection and frequency, will be designed.

- Surveys will be conducted to determine the impact of lake chemistry of new point sources of acid gas emissions, such as the Atikokan Generating Station and of reduced emission levels at existing sources, such as the Sudbury smelters.

- Survey data will be interpreted with respect to the extent of acidification, relationship with geology and other related physical-chemical factors.

- A detailed analysis of the existing data base will be performed to map out areas of low alkalinity and to assess the role of organic acids in controlling lake pH on an extensive basis.

- Once predictive lake chemistry models are developed, the extensive lake data base will provide the basis for province-wide assessment of resources at risk.

ii) Metal and Organic Residue Monitoring

Achievements to Date:

Mercury and lead residue levels in yearling yellow perch from lakes in Muskoka-Haliburton have been monitored since 1978. Over the 1978-1984 period, no significant changes in residue levels were noted. Results of whole fish analyses showed that mercury and lead residues are inversely correlated to epilimnetic lake pH. Fish condition factor is also inversely correlated to Hg and Pb residues. Comparison of Hg residues in yellow perch collected from lakes in three areas of Ontario subjected to different acidic deposition rates suggests that relationships exist between deposition and Hg accumulation.

Between 1977 and 1984, sportfish from some 1,300 locations in Ontario were tested for Hg levels. At a number of locations remote from any obvious point sources of Hg, Hg residues in the edible portion of the larger sportfish are elevated above the 0.5 ppm guideline for unlimited consumption. Work is underway to investigate possible relationships between Hg residues and water quality, physical lake characteristics and indices of acidic deposition. To date, some 680 lakes have data on both Hg in the edible portion of the sportfish and limnological characteristics.

Levels of Hg in adult bass were positively correlated to Hg residue levels in yearling yellow perch for lakes in Muskoka-Haliburton.

Planned Future Activities:

- Trend-through time studies of metal residues in yearling yellow perch and sportfish will be continued, building on the existing data base.

- Investigations of relationships between Hg in sportfish and water quality/atmospheric inputs will be completed using existing data. Sampling of selected lakes to enhance the data base may be necessary.

- Broadscale surveys will be conducted to investigate the occurrence of other types of inorganic and organic contaminants in aquatic biota and to determine their relation to water chemistry and atmospheric deposition.

**D. MOE/MNR Joint Studies**

Objectives:

1. To determine the extent of fisheries resources lost due to, and at risk from, acidic deposition.

2. To determine thresholds of mortality of selected fish species for hydrogen ion and associated toxicants.

3. To test, at the fish population level, the thresholds for pH, aluminum (and acid related toxicants) through study of fish populations through time and comparison of fish populations across chemical gradients.

Achievements to Date:

The Ministry of Natural Resources is studying the fish communities of certain lakes that are being characterized chemically by MOE. Changes in the fish community are being related to concomitant changes in water chemistry or other stresses.

Analysis of fisheries data collected on these lakes has revealed several fish populations with unusual characteristics. As yet, none of these anomalies has been attributed to acidification.

The results of chemical monitoring and in situ bioassays on lake trout spawning shoals indicated that toxic conditions do occur coincident with snow-melt. Sixty-four percent of surveyed lake trout spawning shoals in inland lakes are considered vulnerable to short-term acidification caused by snow-melt.

Chemical monitoring of brook trout spawning sites suggests that the early developmental stages (eggs and sac fry) of brook trout are protected from snow-melt by groundwater which inundates these spawning areas.

In a cooperative MNR/MOE project, the response of lake trout, brook trout, smallmouth bass and walleye populations to acidic deposition is being studied in lakes that span a chemical gradient that includes the suspected species toxic threshold of pH and aluminum. To date, 24 lake trout lakes, 12 brook trout lakes and six smallmouth bass lakes have been studied and the mechanism of loss of lake trout from acidic lakes confirmed.

Results of laboratory experiments of the effects of low pH on the survival of overwintering young of the year smallmouth bass and the eggs and fry of lake whitefish indicate that lake whitefish are more sensitive to low pH than smallmouth bass and the pH tolerance of both species increases with increasing water hardness.

Laboratory studies of the behaviour of lake trout and brook trout fry indicate that during the latter stages of yolk absorption, fry can avoid otherwise lethal levels of pH and aluminum.

Several models have been developed that relate fish community or fish population characteristics to water quality. Three statistical models, using data from regional surveys and intensive fisheries studies, have been developed and the results extrapolated to estimate the current status of

Ontario fisheries. Results of analysis of the existing data on the yield of lake trout and walleye indicate that yield of these species is best predicted by angler effort rather than lake chemical or morphometric characteristics.

Proposed Future Activities:

i) Extensive Surveys and Regional Modelling

° Estimates of brook trout, smallmouth bass, walleye and lake whitefish resources lost and at risk due to surface water acidification will be developed.

° Models relating species richness to lake chemical and morphometric characteristics will be refined.

ii) Intensive Field Studies

° The cause of fish population anomalies such as recruitment failure in low alkalinity lakes will be investigated.

° Baseline fishery data on additional low alkalinity lakes will be gathered.

° The comparative lakes studies will continue a) to examine the relationship between brook trout, walleye, smallmouth bass and lake whitefish populations and water chemistry and b) to test relationships developed for lake trout.

° The effect of surface water acidification on fish populations in running waters will be evaluated.

° The mechanisms of fish population loss will be defined.

° Studies to determine how fish yield responds to reductions in pH and alkalinity will continue.

iii) Laboratory Studies

° Studies to evaluate the effects of pH and aluminum on the survival and development of young smallmouth bass and lake whitefish will be completed.

° The ability of newly hatched lake trout and brook trout to detect and avoid waters of low pH and high aluminum will be evaluated.

**E. MOE/MNR Experimental Lake Neutralization Study**

Objectives:

1. To evaluate the long-term effectiveness of whole-lake liming as an interim mitigative measure to restore acidified lakes and to protect lakes threatened by acidic precipitation.

2. To assess the effectiveness of site-specific liming as a protective measure for important fish habitats and key life stages of fish in acid-stressed lakes.

Achievements to Date:

Methods for calculating the dose of lime and application techniques have been developed; two lakes have undergone whole-lake neutralization. Whole-lake neutralization resulted in decreases in metal levels, with no noticeable detrimental effects on the lakes. Neutralization reduced the toxicity of acidic lake water to lake trout; after neutralization, lake trout were successfully re-introduced to a formerly acidic lake. Subsequent spawning activity of the stocked adult trout has been observed.

Preliminary experiments investigated the feasibility of treating lake trout spawning shoals with crushed limestone. In an acidic lake, incubation of lake trout eggs/sac fry within plots of natural and limestone rubble showed improved survival in the limestone plots. Supporting behavioural studies indicated that spawning lake trout do not avoid natural shoals artificially covered with limestone.

Planned Future Activities:

An overall study report will be completed in 1986/87.

To permit complete evaluation of the long-term biological and chemical responses related to whole-lake neutralization, monitoring will be conducted on the study lakes. Program elements to be continued on an annual basis will include: regular limnological sampling, overwinter lake trout bioassays and lake trout population assessment. As well, complete fish community assessments will be conducted during one of the continuation years.

In follow-up to preliminary experiments, additional, more detailed studies of the effectiveness of shoal liming as a protective measure for early life stages of lake trout will be undertaken.

Completion of the above studies, with final reporting anticipated in 1990/91, will document the biological and chemical effects resulting from whole-lake and site specific treatments and permit evaluation of some of the benefits associated with neutralization.

**F. Ground-Water Studies**

Objectives:

1. To determine ground-water acidity and therefore, allow an assessment of ground-water suitability for consumptive uses.

2. To determine if the atmospheric deposition of acids influences the acidity of ground water.

3. To determine the ground-water contribution to alkalinity in Shield lakes.

4. To identify and study the geologic and hydrogeologic factors that affect this acidity by investigating the cause/effect relationships in a variety of known low pH ground-water situations.

Achievements to Date:

These studies are essentially completed. The major conclusions are that ground water can be a source (in some cases, virtually the only source) of alkalinity in some lakes. However, the amount of water contributed is usually small for most lakes studied on the Precambrian Shield.

A survey of domestic wells has revealed that certain areas of the province have ground water that is quite acidic. However, the acidity of ground water is related to carbonic acid (dissolved carbon dioxide), rather than atmospheric acid deposition.

Planned Future Activities:

This Task is essentially completed and no further work is planned in this area.

**G. MNR Wildlife Studies**

Objectives:

1. To document the impact of acid precipitation on selected wildlife species and wildlife resource user groups.

2. To provide long term monitoring of selected biota.

Achievements to Date:

The Ontario Ministry of Natural Resources has also conducted field studies to determine the relationship between acidic conditions and amphibian distribution and abundance in 40 ephemeral ponds and pools in the Northeastern Region adjacent to Sudbury. In some ponds with depressed pH, levels of inorganic monomeric aluminum were elevated above those which were reported to inhibit hatching success of the wood frog. In 20% of all ponds surveyed, levels of total aluminum, aluminum fluoride and inorganic monomeric aluminum exceeded by several times those reported to reduce hatching success in the American toad.

A three year study was carried out near Killarney in the Northeastern Region to investigate the relationship between water quality variables associated with acidification

and the reproduction of the Eastern Kingbird. Metal enrichment of the diet (emergent aquatic insects) of these birds was also examined.

The major percentage of variation in kingbird reproductive factors measured (including egg weight loss and bone growth) was explained by genetic differences between siblings or by environmental differences between nests. However, an additional amount of variation was explained by water chemistry which was influenced by lake acidification. Metal enrichment of aquatic prey insects was related to acidity in the study lakes. Elevated levels of mercury in Killarney kingbird nestlings were seen in comparison with buffered regions removed from the Sudbury influence.

Data are also available to address the role of natural or organic acidity in the Killarney area wetlands where the wildlife-related studies were carried out. These data indicate that acidity comes predominantly from sulphates and that organic acidity plays a minor role in the Killarney study sites.

The moose is a game species which feeds extensively in aquatic habitat during summer months. Swedish studies in 1981 reported high concentrations of cadmium in moose liver and kidney which, in some instances, exceeded World Health Organization standards. Preliminary work carried out by the Ontario Ministry of Natural Resources in 1984 in one area north of Huntsville showed a broad range of cadmium concentrations in moose kidneys, ranging from trace levels to those which are higher than those acceptable to the World Health Organization. However there was no attempt in this preliminary work to correlate cadmium accumulation with patterns of atmospheric deposition.

Planned Future Activities:

- Further surveys of amphibian habitat to determine the extent of total and inorganic monomeric aluminum and aluminum fluoride levels, which may be inhibiting to amphibian reproduction. (Presence/absence and in situ hatching success of amphibians in these areas.)

- Metal enrichment (Hg, Cd) in selected waterfowl will be compared with that reported in the literature and in prey species.

- Cadmium accumulation in the tissue of moose and other game species will be further studied. This will involve sampling in buffered and non-buffered terrain. Aquatic and terrestrial pathways of metal accumulation in forage species and potentially toxic cadmium levels for moose will also be investigated in cooperation with university personnel.

## TASK 3. TERRESTRIAL EFFECTS STUDIES

### A. Vegetation Studies

Objectives:

1. To compile, as a reference, an annotated bibliography of research related to the effects of acidic deposition on vegetation.

2. To establish the baseline status for nutrient and selected trace elements in tree foliage for future reassessment in order to determine the potential for nutritional and toxic stresses as a result of acidic deposition.

3. To perform greenhouse and field experiments with simulated acid rain in order to investigate the potential effects of increased rain acidity, alone or in combination with other air pollutants, on agricultural crops and forest species under controlled conditions.

4. To develop a method to monitor population changes in lichen and moss flora in relation to acidic deposition and other long range transport air pollutants.

Achievements to Date:

Twelve vegetation baseline sites were established in Southern Ontario in 1980-81. One site was intensively sampled in 1982 to provide information on seasonal elemental variability of the foliage and spatial variability in the tree canopy. A report on these findings is pending.

In the Northwestern Region field work was completed in 1981 for the first round of sampling. Data from 50 sites are currently being evaluated.

A series of vegetation foliage samples was collected from 12 tree species at 14 locations within the High Falls biogeochemical study area. A report summarizing these data is pending.

Four indoor rain simulation chambers were constructed at Brampton in 1982 and have been utilized in simulated acid rain experiments with greenhouse grown plants (e.g. pinto bean, cabbage, cucumber, corn, tomato, white birch, sugar maple, white pine and white spruce). A report on these simulated rain experiments is pending. An experiment is presently underway to investigate the influence of simulated acid rain, ozone and nutrient stress on corn and soybean plants.

A fully automated outdoor rain exclusion canopy and gaseous pollutant reduction system was completed at Brampton in 1984 after two years of construction. To determine the dose-response characteristics of soybean and radish, a trial

field experiment was conducted in 1984. Improvements to the system were made and it became fully automated for the 1985 field season. A maple and white spruce seedling experiment designed to assess the interactive effect of ozone and acidic precipitation was initiated in 1986.

Lichen and moss samples have been collected and chemically analyzed from 45 sites across Ontario. Population inventories at the biogeochemical sites are completed. Plotting of tissue elemental concentrations and the development of mathematical relationships to atmospheric deposition patterns is ongoing. A final report is currently under review.

Proposed Future Activities:

Long range transport of air pollutants, including acidic deposition, can affect forest soils resulting in changes in forest productivity or decline of economically important tree species. Foliage chemistry can be used to evaluate nutrient shortages or elevations of toxic elements which may be related to acidic deposition. Present-day foliage chemistry can be used as a baseline against which future trends can be evaluated.

Lichens and mosses may be used as "early warning" bioindicators of long range transport pollutants as they are known to be sensitive to many air pollutants and derive elements from atmospheric sources. By correlating lichen and moss chemistry with precipitation chemistry, mapping of atmospheric deposition may be feasible. Detailed records of lichen and moss population structures will enable future changes in populations to be detected and evaluated.

Reproducible, simulated rain events will provide reliable results under both greenhouse and field conditions yielding information on injury symptoms to plants, threshold levels of acidity causing effects to plants, effects on growth and yield of crop plants, relative sensitivities and dose response characteristics for selected plant species. Additional knowledge will be gained on the interactive effects between acid rain and $SO_2$, $O_3$, nutrient deficiencies, drought and disease stresses.

**B. Soil Studies**

Objectives:

1. To compile, as a reference source, an annotated bibliography of research related to the effects of acidic deposition on soils.

2. To determine the baseline status of chemical and physical properties of Ontario soils for future reassessment.

3. To develop soil sensitivity criteria and a map of Ontario showing areas sensitive to acid deposition.

4. To conduct simulated acid precipitation experiments with various types of soils to determine both short-term and long-term effects.

Achievements to Date:

A database consisting of 250 soil profiles was completed in 1981 and published in "Ontario Soil Baseline Survey, Analytical Data 1980-81" in 1985. An additional 150 sites were added in 1982-83 and a report on this database is expected in 1986.

A northwestern Ontario report on Pukaskwa Park soils is currently under review.

Preliminary soil data maps have been computer-generated. Further mapping is not planned until soil sensitivity criteria have been fully established.

A report entitled "Preliminary mapping of soils sensitive to acid precipitation in Northeastern Ontario" was completed in 1981.

Preliminary results of 105 weeks of simulated leaching of Southern Ontario soil columns are available. Data from laboratory soil leaching experiments in the NWR are currently under review. The open-top soil column field experiments were started in 1983 and are continuing.

Proposed Future Activities:

Baseline sampling will provide a database against which future soil changes caused by long-range atmospheric deposition may be detected. Such changes may act as an early warning of potential adverse effects on forest productivity and aquatic systems. This database will also be used for soil sensitivity mapping.

Soil sensitivity maps may be used to delineate areas of potential damage by acidic deposition. These findings may be used in the development of abatement strategies.

The soil experiments will yield sensitivity criteria for soil maps. The data will be used to predict the effect of difference acid loadings on different types of soil. These predictions may have a bearing on the choice of abatement strategy. Information for the biogeochemical study will also be generated from these experiments.

**C. Forest Productivity and Decline Studies**

Objectives:

1. To determine the role that air pollutants including acidic precipitation is playing in the decline of sugar maple trees in the Muskoka-Parry Sound Districts of Ontario.

2. To compile and compare current data on forest stand dynamics and productivity in selected woodlots with historical records in the Muskoka-Haliburton area of central Ontario.

3. To investigate the relationship between acidic deposition and forest productivity.

Achievements to Date:

Eleven woodlots for the sugar maple decline study were selected for observation and sampling in 1984 and 1985. An interim report on the 1984 results of this study was published in 1985. A final report on the investigation is expected in 1986.

A province-wide survey for the degree and extent of the decline of sugar maple and other hardwood trees was initiated in 1985. Also, a comprehensive dendrochronology study was carried out in 1985 to develop regional growth chronologies for sugar maple. Data analyses is currently underway. Tree growth patterns will be related to anthropogenic and natural environment factors.

By comparing detailed historical records on forest stand dynamics for selected woodlots to present conditions, the historical evolution of the study woodlots will be determined. The relationship of observed growth patterns to natural environment factors, such as acidic deposition, will be deduced.

Proposed Future Activities:

Possible causes for the decline in sugar maple trees on the study woodlots will be deduced from site quality data, climatic records, management practices and histories of disease and insect defoliations. The elemental database generated from foliage, soil, twig and root sampling will be useful in investigating the physiological response of these trees to environmental stresses, such as acidic deposition.

Studies in root physiology will elucidate the role of nutritional elements (calcium, magnesium and potassium) and toxic elements (aluminum) in the cause of fine root mortality and elemental uptake by sugar maple trees.

Predictive indicator tests of subtle effects on trees prior to the onset of visible symptoms caused by atmospheric pollutants are needed to provide an early diagnosis of forest decline. These tests will show whether forests are in the early stages of being subjected to stress and thus corrective actions can be taken prior to irreversible damage occurring.

There is increasing interest in the role of oxides of nitrogen in the areas of acidification processes and ecosystem damage. Oxides of nitrogen are involved in the formation of

ozone in the atmosphere and both $NO_x$ and $O_3$ are being implicated as being involved in the forest decline problem. In addition, recent studies on forested ecosystems in Scandinavia have now demonstrated that these ecosystems are no longer capable of absorbing deposited nitrates and therefore, nitrates are entering the aquatic components of these systems. Such phenomena require investigation in the Ontario setting both in the terrestrial studies and in the biogeochemical studies (Task 4).

## TASK 4. BIOGEOCHEMICAL STUDIES

Objectives:

1. To determine the importance of and the role of terrestrial systems and the interactions between components of the terrestrial systems (soil, vegetation) and aquatic systems (lakes, streams) with respect to acidic deposition.

2. Using modelling techniques, to predict the effect of acid deposition on elemental cycling, storage and depletion processes in terrestrial ecosystems and the linkage to lake acidification.

Achievements to Date:

In the Muskoka-Haliburton area, two contrasting terrestrial watersheds were selected for study. The monitoring of element and ion transfer pathways as well as the documentation of element stores has been ongoing. Incident precipitation, throughfall, stemflow and soil leachate are being monitored. Litter decomposition rates, forest inventories, biomass elemental surveys, soil surveys and soil mass determinations are ongoing projects. A major progress report was submitted in 1985.

Northwestern Ontario's biogeochemical study area was selected in late 1982. Watershed monitoring was established during 1983. Routine monitoring for air quality ($SO_2$, $NO_x$, $O_3$), wind speed and wind direction, incident precipitation, precipitation throughfall, lysimeter leachate, litterfall, litter decomposition, stream flow and stream water quality are being carried out. Forest inventories, vegetation biomass and soil surveys have been completed. Fact sheets are publicly available. A major progress report was completed in early 1985.

The biogeochemical study at High Falls in the Northeastern Region was established in 1982 and is comparable in both method and status of data to the Northwestern Region's study. Reports prepared include: "The Biogeochemical Study in Northeastern Ontario: Status Report", 1983; a detailed procedures manual specific to the High Falls site; a report entitled "Forest Characteristics of the High Falls Biogeochemical Study Site", 1984; and a report entitled "An Annotated Checklist of Vertebrate Species of the High Falls Biogeochemical Study Site". An annual report was submitted for work completed in FY 1985/86.

During FY 1985/1986, the current design of the biogeochemistry program was reviewed and integration with the aquatic program was initiated.

The field studies for the Hawkeye Lake, Plastic Lake and Harp Lake sites were redesigned for FY 1986/87. Monitoring at High Falls will be discontinued. Data interpretation,

however, will be emphasized during the next fiscal year before a final decision is taken with respect to the continuing field operation of any of the sites.

Proposed Future Activities:

Biogeochemical studies will provide detailed information on the physical, chemical and biological state of the study watersheds and will document changes in this state with time. Such information is a prerequisite for quantifying the magnitude of chemical fluxes between ecosystem components and evaluating the role of acidic deposition in altering these fluxes. The study will show how interactions occur between precipitation, vegetation and soil and how the chemistry of water discharged to aquatic systems is affected.

Ontario's biogeochemical study sites, located within three different zones of atmospheric deposition, will allow "gradient effects" of acidic loadings to be investigated. Modelling the relationships within these watersheds could yield threshold levels of acidic deposition that could be tolerated by different ecosystems. Biogeochemical studies may provide data to enhance the understanding of i) sulphate deposition target loadings and ii) the effectiveness of future abatement strategies.

Several specific projects were deemed of great importance and study designs have been developed to address the effect of acid deposition on the natural mineral weathering rates of bedrock and till on the Precambrian Shield and on the aluminum and sulphur cycles.

These biogeochemical studies will also investigate the role of nitrogen as a nutrient in terms of biomass accumulation and the contribution of nitrate and ammonium to the acidification of soil water.

In addition, a whole-watershed manipulation comparable to the Norwegian RAIN project will be considered. The input of strong acid to a watershed will be reduced to simulate a reduction in $SO_2/NO_x$ emissions and the changes in soil and water chemistry will be studied.

## TASK 5. SOCIO-ECONOMIC INVESTIGATIONS

The socio-economic component of the APIOS program is intended to identify, measure and compare the social and economic implications of different scenarios for the control of acid deposition, including the option of doing nothing. These evaluations will give relevant parties a more comprehensive idea of the consequences of specific courses of action than will the various scientific studies by themselves. The socio-economic component thus will provide frameworks and methods that can be used to integrate scientific and socio-economic data and information to produce policy-relevant assessments of control strategies.

Interested parties can then use this information, along with other considerations, to make choices, develop objectives or establish bargaining positions as required.

To generate the relevant methods and information, a three-part framework was developed. The three parts of the socio-economic component include:

- assessments of the social and economic effects of acid precipitation and the benefits of reducing these effects in Ontario (Damages and Benefits);
- assessments of the costs and other implications of $SO_2$ and $NO_x$ abatement as well as the costs of "defensive actions" (e.g. lake liming) to offset the effects of acidification (Costs of Abatement and Mitigation);
- development of techniques and tools to aid in the evaluation of control or mitigation strategies (Strategy Development and Evaluation).

### A. Damages and Benefits Studies

Objectives:

1. To identify and estimate the present and future bio-physical effects that may be caused by acid deposition, using results of aquatic and terrestrial scientific studies.
2. To develop procedures, methods and models to determine monetary values associated with the various tangible and intangible effects of acid deposition.
3. To develop and apply methods to assess the uncertainties associated with acid deposition effects and their relevant monetary values.
4. To produce estimates of current and potential bio-physical effects and their social and/or economic significance.
5. To determine the potential benefits of acid deposition control programs in terms of the prevention of bio-physical damages and their associated monetary values.

6. To determine the distribution of estimated damages and benefits over regions, groups, economic sectors and time.

7. To provide feed-back to aquatic and terrestrial scientists as to the appropriate information required to undertake policy assessments.

Achievements to Date:

Four major investigations concerning acid rain and one concerning ozone have been completed in this component.

° a review of amenity value survey methodologies;

° the amenity value survey;

° an assessment of the significance of acid precipitation on tourism and outdoor recreation in Ontario;

° development of models to estimate acid deposition effects on forestry, commercial fisheries, agriculture, commercial furs and selected structural materials in Ontario.

The Amenity Value Survey yielded estimates of the amounts of money respondents were willing to pay, in terms of increased prices and taxes, to prevent the deterioration of aquatic environments by acidification. Information on respondents' knowledge of acid precipitation and its effects was collected as was attitudinal information relevant to environmental protection.

The Outdoor Recreation and Tourism study concluded that only aquatic-related recreational activities such as fishing, swimming, scuba diving, water skiing and, possibly, boating could be adversely affected by acid deposition. Health effects from contact with acidified surface waters were highly unlikely. Finally, it was concluded that the prices of cottage properties have so far not been affected by acid precipitation and that there is no reliable way to determine, a priori, whether these prices ever will be affected.

Data on aquatic recreational activities in Ontario were collected and a procedure for estimating the potential changes in sport fishing activity that might result from a loss of fish populations was developed and applied. A substantial amount of useful data was assembled and a number of issues and relationships which require more study were identified.

A computer model was developed to estimate the bio-physical effects of acid deposition throughout Ontario and their associated economic values. Models for five key sectors were developed:

° agriculture;
° forestry;
° commercial furs;

° commercial fishing;
° structural materials.

Although the dose-response relationships used in the models are tentative and subject to review and revision, initial analyses reveal a number of important insights:

° potential effects on terrestrial receptor-categories (forests and agriculture) may be far more extensive than had previously been considered;

° simplistic, linear assumptions cannot be made about the effects of acid deposition since there are many intermediate relationships and there are some potentially beneficial, as well as adverse, effects that may be due to acid deposition;

° data and information gaps were explicitly identified and conveyed to MOE researchers.

Ozone is another product of long range atmospheric processes and transport. The adverse effects of ozone on crop plants are also well documented.

In cooperation with the Phytotoxicology Section of the Air Resources Branch and the Southwestern Regional Office, an in-house study of the beneficial effects of reducing ozone concentrations in Ontario was carried out. Based on dose-response relationships for each crop type in Ontario provided by the Phytotoxicology Section, estimates of the increased crop production that could result in different regions of the province were prepared. Using the average farm-gate prices for 1981 and assuming no effects on prices due to the potential increases in production, annual values of the extra crop production that might result from reduced ozone levels could range from $9 to $23 million.

The Financial Value Models for materials, forests and agriculture, and the relevant data bases are being reviewed and updated. This effort will make the models more reliable and credible and permit estimates of the damages that acid rain might cause or the benefits of its control.

Planned Future Activities:

The emphasis on future work will be to continue the dialogue with aquatic and terrestrial scientists concerning the generation of policy-relevant dose-response information and relationships. Models and methods will also be revised and refined as new data and information become available. It is emphasized that all of the methodologies being applied are transferable to other environmental issues.

The following investigations are proposed under the auspices of APIOS over the next two fiscal years:

° economic and social effects and benefits of the control of ozone and other oxidant pollutants;

- an assessment of the relative importance of the "acidified" and "acid sensitive" categories of lakes in Ontario;
- further applications of the financial value models.

**B. Costs of Abatement and Mitigation**

Objectives:

1. To determine the direct and indirect costs of precursor emissions abatement.
2. To determine the direct and indirect costs of program and actions to mitigate or offset the effects of acid deposition.
3. To assess the economic and financial implications of these costs.

Achievements to Date:

A Federal-Ontario Task Force was convened to examine $SO_2$ control options for the Inco Ltd. and Falconbridge Nickel Mines, Ltd. smelters in Sudbury, Ontario. The Task Force Report was released in the fall of 1982.

A key finding of this study was that the technical options were available to both firms that would appreciably reduce $SO_2$ emissions and still earn a positive financial return on investment. Inco is currently studying the technology identified in the Task Force Report and may implement a version over the next several years.

A great deal of in-house work has been carried out concerning the costs of $SO_2$ abatement at Ontario Hydro and other major industrial sources in Ontario. This work was incorporated into the "Countdown Acid Rain" Program.

Planned Future Activities:

Future work on costs and their implications will be in support of the provincial $SO_2$ and $NO_x$ abatement strategy development. This will involve generation of abatement cost functions and the assessment of financial impacts on firms as required.

**C. Strategy Development and Evaluation Tools**

Objectives:

1. To develop tools and procedures that will aid in the development and evaluation of strategies to control LRTAP and its effects.

2. To evaluate various strategies on the basis of criteria such as cost minimization, benefit maximization, cost effectiveness, distribution of costs and benefits, etc.

3. To evaluate economic methods to induce implementation of abatement actions.

Achievements to Date:

A computerized computational procedure called "the screening model' has been developed and applied. This is a linear-programming based optimization program which can be employed to determine least-cost configurations of $SO_2$ abatement at the multitude of point sources in eastern North America to achieve deposition targets at specific receptor areas.

The screening model was used to determine control costs and their distribution among sources and jurisdictions of different control strategies and abatement programs. These results were used in the inter-provincial LRTAP strategy deliberations. Screening model results were also used in the development of the "Countdown Acid Rain" Program.

Another study reviewed economic incentive policies such as emission penalties, emission rights and surety bonds and examined the application of these policy instruments to major $SO_2$ polluters. The study indicated that there were potential cost savings associated with the application of these policies but that there were significant perceptual difficulties that constitute barriers to the adoption of these instruments.

In addition, Ontario had the lead role in an Intergovernmental Work Group to investigate the application of economic incentive policy instruments and financial assistance programs to major $SO_2$ emitters throughout Canada.

Planned Future Activities:

Draft legislation and administrative guidelines are now being developed to implement one type of economic incentive policies known as The Financial Security Deposit Program.

Further applications of the screening model will be worked upon as needed. Analyses of the sensitivity of model results to variations in certain input data are also being conducted.

## TASK 6. LEGAL INITIATIVES

### A. Provincial Initiatives

Objectives:

1. To assess the effectiveness of the various legal instruments available.

2. To investigate alternative legal mechanisms to induce compliance.

Achievements to Date:

Prior to 1980, Ontario had controlled its point sources of $SO_2$ through Control Orders which were issued based on provincial ambient air quality criteria.

However, as the extent and severity of the acid rain problem continued to increase, the Ontario Cabinet enacted Ontario Regulation 712/80 applying specifically to the Copper Cliff smelter complex of Inco Limited. A Regulation was used in this unique manner since it was the strongest legal measure available to the Province.

The instrument of a Regulation was also resorted to in order to control emissions of sulphur dioxide and nitric oxide from Ontario Hydro.

Planned Future Activities:

Ontario has decided to make further significant reductions in sulphur dioxide emissions by 1994, in addition to its agreed share of the eastern Canada commitment to reach a ceiling of 2.3 million tonnes.

For further information on Ontario's Acid Gas Control Program for 1986-1994, please refer to the report entitled "Countdown: Acid Rain".

### B. Canada/U.S. Initiatives

Objectives:

1. To persuade the U.S. Environmental Protection Agency to take into account LRTAP considerations in the enforcement of Sections 110, 115 and 126 of the present U.S. Clean Air Act.

2. To support the Canadian federal government in the negotiating process with the U.S.

3. To intervene at the appropriate level in the U.S. system in order to persuade States not to relax $SO_2$ State Implementation Plans that would adversely affect Ontario.

4. To investigate the feasibility of supporting or initiating legal suits in the U.S. and take appropriate action.

Achievements to Date:

Ontario has intervened in several U.S. States and with the U.S. E.P.A. under Section 110 of the U.S. Clean Air Act in opposition to proposed relaxations of State Implementation Plans (S.I.P.s) for $SO_2$ or extensions in compliance dates. The Province of Ontario's submissions were instrumental in two denials in the State of Michigan.

In June 1981, Ontario also appeared at the U.S. E.P.A. Section 126 Hearing held in Washington, D.C. in support of the States of New York and Pennsylvania in their petition concerning Interstate Pollution. Since E.P.A. still had not made a ruling by early 1984, these states plus several environmental groups filed a legal suit against the U.S. E.P.A. that 1) the Administrator had violated his mandatory duty under Section 126 to issue a final decision on the petitions regarding interstate air pollution by the deadline (within sixty days) specified in the Statute and 2) that the Administrator had violated his mandatory duty to determine which states are contributing to air pollution which endangers the public health and welfare of Canada and to give notice to the Governors of such states to revise their S.I.P.s in order to prevent or eliminate harm.

The Court ordered E.P.A. to make a ruling under Section 126. On December 10, 1984, the E.P.A. announced its decision to deny the Section 126 petitions since it determined that the States did not adequately support their claims of injury. An appeal is under consideration.

In July 1985, a U.S. federal court judge ruled in favour of the plaintiffs under Section 115 and ordered the U.S. Environmental Protection Agency to reduce acid causing emissions in seven Midwestern and border States, (Kentucky, Ohio, Indiana, Illinois, West Virginia, Michigan and Tennessee) beginning next April. The E.P.A. has filed an official appeal, saying the court imposed deadline was "inadequate". Ontario requested intervenor status on October 24 in the appeal process. A hearing date for the appeal has not been set yet.

On the same day, Ontario also requested intervenor status in a similar appeal of power companies, the E.P.A. and the State of Ohio against the Section 115 ruling made by former Adminstrator Costle. Oral argument was heard by the court on May 15, 1986 and judgement has been reserved.

Planned Future Activities:

The Province will continue to intervene under Section 110 as the need arises. A decision to intervene in any given case will be based on the individual merits of that case.

Any further actions under Sections 126 will be monitored and the province will offer support and evidence when and if necessary.

Ontario will become involved in the Section 115 Hearings as soon as the dates are set.

Other legal initiatives will be considered as they arise.

## TASK 7. PUBLIC RELATIONS INITIATIVES

### A. Provincial Initiatives

Objectives:

1. To inform a broad segment of Ontario residents about the issues involved in acid rain and the government's programs, achievements and new initiatives to meet this challenge.

2. To provide cottagers and other special interest groups with specific information relevant to their special concerns about acid rain.

Achievements to Date:

A general information brochure entitled "The Case Against the Rain" was produced in 1981 and since that time has received wide distribution throughout the province. A videotape with the same title has received continued use at displays and open houses.

Since the Muskoka-Haliburton area is extremely sensitive to acid precipitation and since it is a prime recreation location in southern Ontario, many intensive research activities are underway there. The focus of this research has led to the establishment of a major research facility at Dorset. The development of this facility has taken several years, however, July 1983 marked the official opening of the centre. The facility is now open to the general public and tours are available upon request.

Besides several Open Houses at Dorset, official Open Houses have been held in Haliburton, Sundridge, Bracebridge, Parry Sound, New Liskeard, the Kortright Centre and Meynouth. In addition, a sensitivity map for lakes in Algonquin Park has been prepared and is on display at the Park Entrance.

An "Acid Sensitivity Survey of Lakes in Ontario" is produced annually and has proven invaluable in responding to requests from cottagers for information concerning the status of their lakes.

Recently, a weekly acid rain report prepared jointly by Environment Ontario and Environment Canada has been released to the public. This report summarizes the pH of rain and snow events every week at five locations: Kejimkujik National Park in Nova Scotia; Montmorency Forest in Québec; and Chalk River, Longwoods and Dorset in Ontario.

In addition, ongoing activities include media relations, the maintenance of slide and graphic resources and the preparation and production of speeches and statements.

Planned Future Activities:

Flyers will be prepared to address specific issues of the acid rain problem such as the impact on forestry and the effects on water quality and fisheries. As well, a complementary videotape package is under consideration.

Ongoing activities include the updating of fact sheets and the preparation of new fact sheets, statements and press releases. Open Houses will be scheduled at different locations throughout the province as the need arises.

**B. Canada/U.S. Initiatives**

Objectives:

1. To increase general public awareness in the U.S. concerning the serious nature of the acid rain problem created by U.S. power plants and other industrial sources of sulphur and nitrogen oxides.

2. To provide more intensive awareness and understanding of the Ontario/Canada acid rain problem among special and key audiences, including U.S. media, federal and state elected officials.

3. To encourage a more positive attitude in the U.S. toward firm pollution control and abatement policies.

Achievements to Date:

Since FY 1981/1982, the public relations program has been expanded to inform the U.S. of the nature and extent of the problem in Ontario in order to obtain support for an abatement program.

This objective continues to be met through the showings of our acid rain film 'Crisis in the Rain'. This film has been made available through the Canadian Consulate Offices in the U.S. By April 1, 1984 this film was seen by 134,060 viewers in direct showings and four million via TV in Ontario and the United States. In addition, the 'Case Against the Rain' has been widely distributed to U.S. audiences.

Other activities include the continuous appearance by Ministry staff at relevant Hearings and Conferences in the U.S.

The American campaign has included tours of the research facilities at Dorset as well as field trips and scientific briefings for senior American journalists of leading publications, U.S. legislators, Congressional Aides and the U.S. NAPAP Task Force. These tours resulted in increased coverage of the acid rain issue by U.S. media and a heightened understanding of the Canadian position by U.S. legislators and politicians.

Planned Future Activities:

Due to the American Administration's anti-controls position, our campaign in the U.S. takes on increasing importance.

Once prepared, the Acid Rain Flyers should be widely distributed. As well, the recent eastern Canadian decision to take unilateral $SO_2$ control action and Ontario's new $SO_2$ control program will be highlighted.

Videotapes incorporating the recent developments in research and abatement in Canada, once completed, will be widely distributed for showings to numerous U.S. audiences.

In addition, tours are planned in order to target the coal burning states and uncommitted areas such as the U.S. south and southeast.

## APPENDIX I

### PROGRAM ORGANISATION

The extensive environmental effects and the complicated control programs for acid rain fall under the jurisdictions of several Ministry Branches, several Provincial Ministries and both the Provincial and Federal Governments. As a result, a comprehensive project management structure has been put in place to ensure an efficient, results-oriented program. The value of this approach has been proven in that we have kept on top of the problem in the eyes of the public and that the high quality of our research is recognized worldwide. Our scientists act as advisors for at least four other countries. During the preparation of reports under the Canada/U.S. Memorandum of Intent, Ontario's research results largely established our case and our staff prepared a large portion of the reports. (Program organisation is outlined in Figure 1.)

Work Groups: For each area of study (atmospheric, aquatic, terrestrial, biogeochemical and analytical), a team of scientists from all relevant Branches and Ministries establish the research needs and priorities. Each area has its own specific goals and assures the credibility of its research through a documented and operational quality assurance program.

Science Committee: Program supervisors from all appropriate Branches and Ministries ratify the research priorities and then allocate the available manpower and money to the program areas.

Acid Rain Committee: Branch Directors and senior Ministry staff from MOE, MNR and MIGA establish overall policy and program directions and ratify the program resource allocation proposed by the Science Committee.

Coordination Office: This Office provides overall leadership and conducts the budget preparation and management during the year for the program. The Office provides secretarial support to the above Committees, prepares progress reports, program overviews and annual reports. Policy options are usually developed by the Coordination Office for consideration by the Acid Rain Committee.

In addition to our own internal structure, Ontario co-chairs a Federal/Provincial Steering Committee dealing with Canadian policy and a Federal/Provincial Technical Committee which coordinates the research efforts of federal and provincial governments. The Federal Government has a Coordination Office similar to Ontario's and the Coordinators keep in close touch on activities. (See Figure 2.)

In addition to coordination of Federal and Provincial research and monitoring, Ontario participates in several international studies as described in Table 1.

FIGURE 1: LRTAP COMMITTEE STRUCTURE - ONTARIO

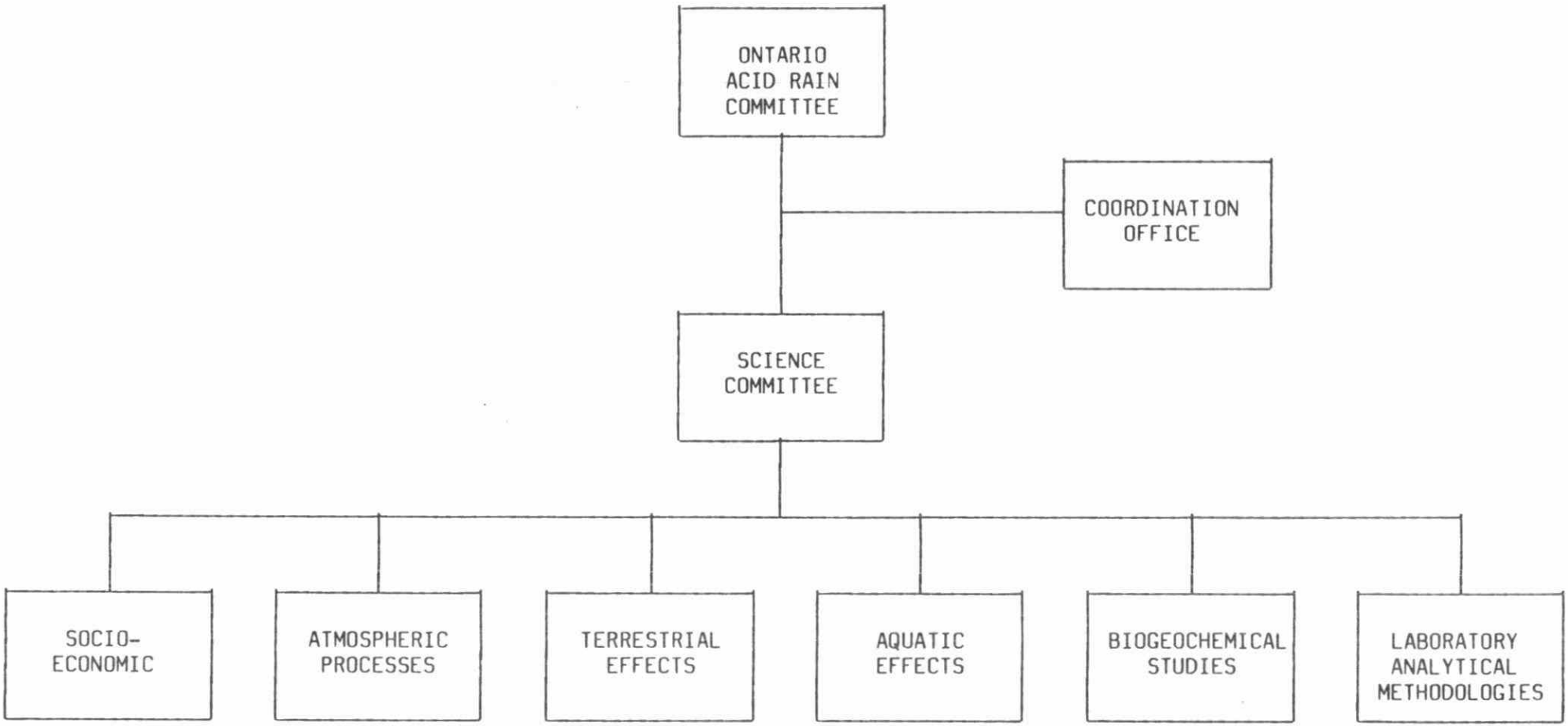
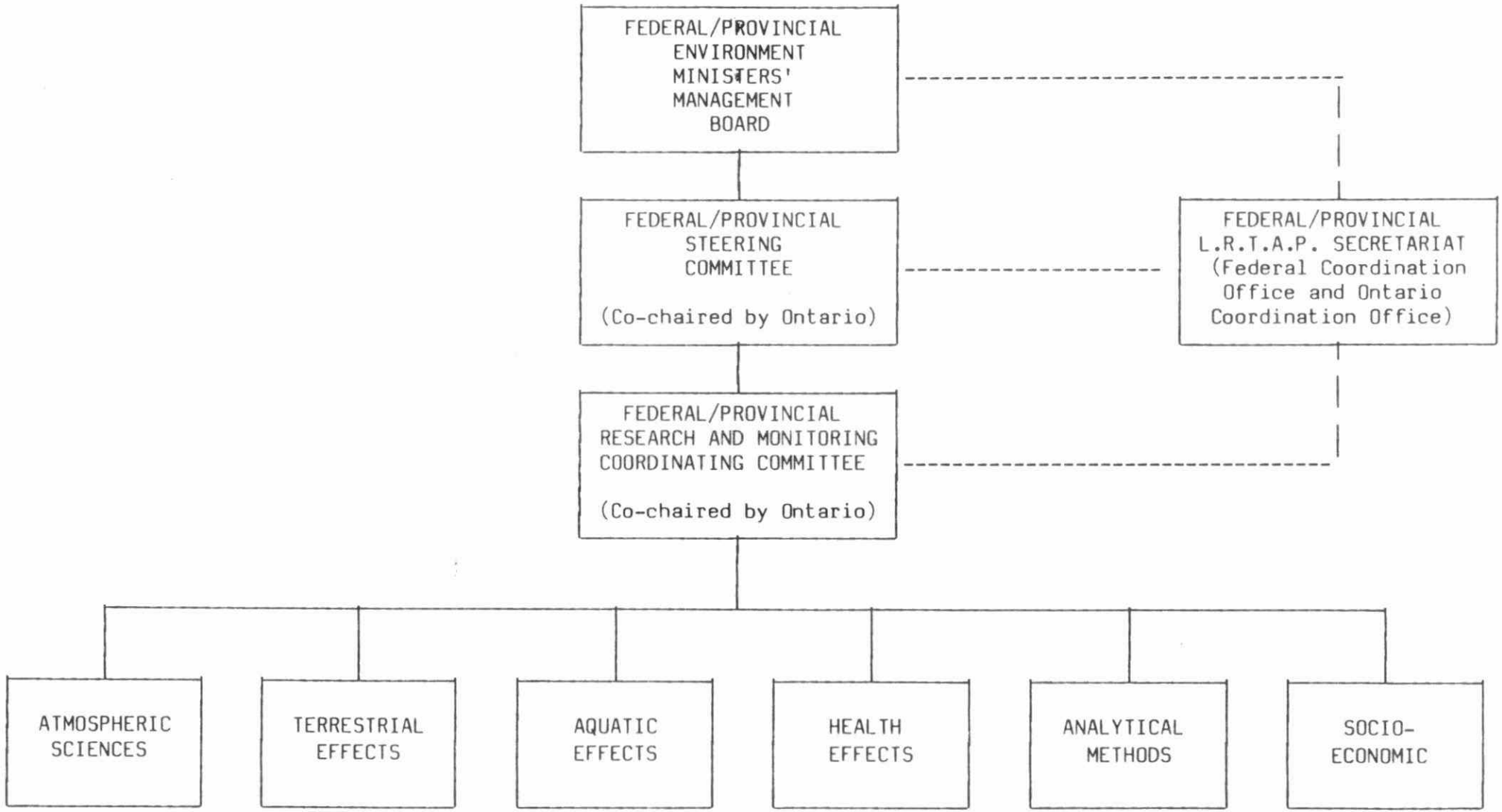


FIGURE 2: LRTAP COMMITTEE STRUCTURE - FEDERAL/PROVINCIAL



## APPENDIX II

## INTERNATIONAL LRTAP PROJECTS - MOE CO-FUNDING

| Project Title | Funding Agencies | Purpose |
|---|---|---|
| Acid Deposition and Oxidants Model | Environment Ontario<br>Atmospheric Environment Service<br>Umweltbundesamt (West Germany)<br>Environment Québec<br>State of Minnesota<br>State of New York | To improve predictions of source/receptor relationships, i.e. what areas are affected by what sources? |
| Rain Acidity Interlaboratory Study of Damage to Agricultural Crops | Environment Ontario<br>Boyce Thompson Institute<br>Argonne International Laboratory<br>Corvallis Environmental Research Laboratory<br>Oakridge National Laboratory<br>Brookhaven National Laboratory | To measure the effects of different pH's on crops and to standardize techniques and procedures.<br><br>Study has been completed. A similar study is being developed for exclusion canopy work. |
| Reversing Acidification in Norway - NIVA | Environment Ontario<br>Norway<br>Sweden<br>Environment Canada<br>United Kingdom | To test hypotheses on watershed sensitivity and to measure watershed response to reductions and increases in acid loadings. This issue has been recently raised by the U.S. E.P.A. as an impediment to designing a control program. |

## INTERNATIONAL LRTAP PROJECTS - MOE PARTICIPATION

| Project Title | Participating Agencies | Purpose |
|---|---|---|
| Aluminum Biogeochemistry in Forested Watersheds | Electric Power Research Institute<br>Environment Ontario<br>Environment Canada<br>United States<br>West Germany<br>Norway<br>Sweden<br>United Kingdom | To identify and quantify the release, transport and toxicity of aqueous aluminum in the natural environment. Aluminum is toxic to both fish and trees. |
| Deposition Monitoring Intercomparison | Environment Ontario<br>Environment Québec<br>Atmospheric Environment Service<br>National Atmospheric Deposition Program | To assess comparability of Ontario, Québec, Canada and U.S. deposition monitoring results. |
| Fisheries Loss Assessment Program | NAPAP<br>Environment Ontario<br>Ontario Ministry of Natural Resources<br>EPRI<br>Environment Canada | To assist NAPAP in the design of a program to assess fisheries loss in the U.S. related to acidic deposition. |

| Project Title | Participating Agencies | Purpose |
|---|---|---|
| Human Health Effects Related to Aquatic Effects of Acid Deposition | EPA<br>Environment Ontario<br>Various State Health Agencies | MOE has been invited to sit on a Committee of experts to determine the exact nature and extent of these human health effects. |
| Informal Calibrated Watershed Modelling Group | Environment Ontario<br>Environment Canada<br>United States<br>Norway<br>Sweden | To compare results and ideas on watershed studies. The work defines effects of acid rain and develops target loadings to prevent damage. |
| Interlaboratory Quality Assurance | Government and private laboratories in Canada and the U.S. (over 50 labs involved, including MOE) | To ensure the validity and compatibility of all data collected under LRT programs in North America. |
| Lake Acidification Mitigation Program | EPRI<br>Clarkson College<br>Environment Ontario | MOE has been requested to provide advice and information concerning lake liming projects. |

| Project Title | Participating Agencies | Purpose |
|---|---|---|
| National Surface Water Survey | EPA<br>Environment Ontario<br>Environment Canada | To characterize current water chemistry of lakes and streams in five U.S. Regions. MOE has been requested to assist in the development of the survey design. |
| Ontario/Minnesota Agreement | Ontario<br>Minnesota | To exchange information on acid rain; to cooperate on specific projects (atmospheric modelling, RAIN - NIVA, aquatic effects in a medium deposition area). |
| Ontario/NADP Intercomparison Study - Ely, Minnesota | Ontario<br>National Atmospheric Deposition Program | To improve comparability of data. |
| Ontario/New York Agreement | Ontario<br>New York | To exchange information on acid rain; to cooperate on specific projects (deposition measurements and comparisons, possibly some mercury deposition and lake liming studies). |
| Ontario/Michigan Agreement | Ontario<br>Michigan | At the signing stage. |
| Ontario/Ohio Agreement | Ontario<br>Ohio | In progress. |

## APPENDIX III

## APIOS BUDGETS FY 1979/1980 TO FY 1985/1986

| | M.O.E. | M.N.R. | TOTALS |
|---|---|---|---|
| 1979/1980 | 500.0 | 0.0 | 500.0 |
| 1980/1981 | 3,467.0 | 1,030.0 | 4,497.0 |
| 1981/1982 | 5,724.0 | 1,290.5 | 7,014.5 |
| 1982/1983 | 8,868.5 | 1,464.6 | 10,333.1 |
| 1983/1984 | 8,735.8 | 1,493.4 | 10,229.2 |
| 1984/1985 | 8,712.2 | 1,535.4 | 10,247.6 |
| 1985/1986 | 9,421.4 | 1,742.0* | 11,163.4 |
| TOTALS | 45,428.9 | 8,555.9 | 53,984.8 |

* Expected MNR Expenditure